Agricultural Systems 166 (2018) 124–134

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Review

A review of greenhouse gas emissions from the agriculture sector in Africa

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ARTICLE INFO

Keywords:
Enteric fermentation
GHG intensity
Crop management
Livestock production
Smallholder farming

ABSTRACT

Agricultural activities contribute to greenhouse gas (GHG) emissions to the atmosphere. The GHG emissions from agriculture in Africa are among the fastest growing emissions in the world. The increasing food demand due to population growth in Africa and other parts of the world will continue to influence emissions in the continent. This study provides a review of GHG emissions from the agriculture sector in Africa between 1994 and 2014. The policy requirements for the mitigation of the emissions in the continent are also discussed. The continent was divided into five broad regions according to prominent agro-ecological zones. The data analyzed were from the national GHG inventory reports, national communications to the United Nations Framework Convention on Climate Change, Food and Agriculture Organization of the United Nations, Emissions Database for Global Atmospheric Research and material from the literature. The highest and lowest annual emissions from these sources defined the ranges of emissions, except in 2014 when there was only a single source. Between 1994 and 2014, the GHG emissions from agriculture in Africa increased at an average annual rate of between 2.9% and 3.1%. The emissions ranged between 0.44 Gt and 0.54 Gt CO_2 equivalent in 1994, 0.66 Gt and 0.79 Gt in 2010, and 0.87 Gt in 2014. The rates of emissions are not homogeneous in all regions of the continent. East Africa and Southern Africa are the largest producers of emissions from agriculture in the continent with 34% and 27% respectively. The regions with the lowest emissions are Central and North Africa with a maximum of 10% of the total emissions from the continent. Enteric fermentation is the largest source of emissions from agriculture in the continent with more than half of the total. Focussed research is required to remove large uncertainties that exist in the GHG emissions from Africa so that appropriate mitigation plans can be developed. As a result of Africa's high vulnerability to the adverse impacts of climate change, the continent's main focus is on building resilience and improving food security. Plans to mitigate GHG emissions are not explicit and only appear as secondary or co-benefits of adaptation. Consequently, mitigation of emissions from agriculture may need to be identified and formulated within the broad food security and economic development but contextualized to the main farming systems practised in the continent.

1. Introduction

Agriculture is the primary sector of almost every African economy (Saghir, 2014; Valentini et al., 2014; Ba, 2016). About 65% of the total labour force in Africa is employed in the agriculture sector, which contributes about 32% of the continent's gross domestic product (GDP), reflecting the relatively low productivity in the sector (Chauvin et al., 2012; Ba, 2016). Agricultural land expansion (extensification) has been an important component of production growth in places such as Africa and Latin America (Tilman et al., 2011; Herrero et al., 2016). Production in Africa could also be increased by agricultural intensification (i.e. achieving higher yields through increased inputs, improved agronomic practices, improved crop varieties, and other innovations) (Hickman et al., 2011; Tilman et al., 2011). In developing countries, agriculture is a crucial sector for driving the green economy (Musvoto et al., 2015). However, land clearing, soil cultivation, and the manufacture and use of nitrogen (N) fertilizer all emit greenhouse gases [GHG] (Tilman et al., 2011).

Despite impressive economic performance of not less than 4.5% during the first decade of this millennium in sub-Saharan Africa (SSA), agricultural transformation has been slow and growth sluggish (Chauvin et al., 2012). Agricultural production in SSA grew at an average annual rate of between 2.6% and 3.1% from 1961 to 2008 (Fuglie and Rada, 2013). Annual agricultural GDP growth in SSA averaged 2.3% in the 1980s (lower than the average population growth) and 3.8% during the 2000s but this growth has been mostly

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https://doi.org/10.1016/j.agsy.2018.08.011
Received 2 October 2017; Received in revised form 8 June 2018; Accepted 20 August 2018
Available online 28 August 2018
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based on area expansion (Chauvin et al., 2012; Fuglie and Rada, 2013). Total food production in SSA has been growing but at a very slow rate of less than 1% per year (Salami et al., 2010; Chauvin et al., 2012). There are varying factors that lead to the slow growth of agricultural output in Africa. Low spending on agriculture by most African farmers (average of 1% to 6% of total expenditure since 1980), low adoption rates of new technologies, inaccessibility to markets for both inputs and outputs, continuous decline of soil nutrients, and an unskilled labour force are prominent impediments to agricultural growth in the continent (Salami et al., 2010; Chauvin et al., 2012; Fuglie and Rada, 2013).

A total of 85% of annual available fresh water in the continent is being withdrawn for agricultural use (Inocencio et al., 2003). Agriculture is the biggest user of water in Southern Africa, accounting for 60% to 75% of total water use (Lange et al., 2007; Blignaut et al., 2009; Lorentzen, 2009). Agriculture uses 75% of water withdrawals in West Africa although only around 1% of the arable land is irrigated (ECOWAS, 2006). The agricultural sector is responsible for nearly 75% of total water withdrawal in the Nile basin where even small-scale farming in the drier lower basin relies largely on surface water and groundwater (EEAA, 2010; Swain, 2011). Approximately 50% of potential arable land in the Nile basin is irrigated, of which 98.7% is in the climatically dry Egypt and northern Sudan region (Swain, 2011). Use of water in agriculture especially during irrigation influences N dynamics in the soil and ultimately nitrous oxide (N_2O) emissions.

Currently livestock is one of the fastest growing agricultural subsectors in developing countries (Thornton, 2010). East Africa had the most heads of cattle and buffalo between 2000 and 2011 due to the export demand to the Middle East (Gerber et al., 2013; FAO, 2014, 2017b). Ethiopia has the largest national livestock population (most of which are local breeds fed on natural pastures and crop residues) in Africa (FAO and NZAGGRC, 2017) and is ranked tenth in the world (FAO, 2015; Mayberry et al., 2017). Most ruminants raised for meat in SSA have lower feed efficiencies (Herrero et al., 2013). Livestock in grazing systems consume mostly grass, whereas those in mixed systems consume a wide array of feeds (Herrero et al., 2013; Moeletsi and Tongwane, 2015). In recent decades, increasing numbers of animals are raised in intensive production systems where they are fed a diet rich in protein content (Koneswaran and Nierenberg, 2008; Scholtz et al., 2013; Herrero et al., 2013; Gaitan et al., 2016).

Use of fertilizer per hectare (ha) of arable land is increasing in Africa but the consumption rate remains low (FAO, 2013, 2014; Ba, 2016; Lu and Tian, 2017). Average fertilizer applied on croplands in SSA peaked at around 10 kg of N ha^{-1} in the 1980s and has since fallen to under 8 kg ha^{-1}, representing rates far below those of other developing countries (Fermont et al., 2010; Hickman et al., 2011; Fuglie and Rada, 2013; Tadele, 2017). Fertilizer application rates in other parts of the continent are higher and average about 35 kg ha^{-1} since the mid-1990s (Salami et al., 2010; Fuglie and Rada, 2013; EEAA, 2010; Tongwane et al., 2016). Mineral fertilizers only contributed 25–29% of the overall total N input in Africa, a reflection of the low purchase of mineral fertilizers in many countries of the continent (Liu et al., 2010). The global average N use intensity was 94 kg ha^{-1} in 2005 (Tilman et al., 2011). Extensive planting of soybeans and other leguminous crops in the continent make biofixation the single largest N input in the continent (Liu et al., 2010). Fertilizer applied during crop production is heterogeneous among African countries (Jayne and Rashid, 2013; Sheahan and Barrett, 2017). However, blanket application of fertilizer in Africa remains common (Jayne and Rashid, 2013; Ezui et al., 2016). In Egypt, where the area of cultivated crops increased significantly, application of N increased by 144% between 1990 and 2000 and farmers apply over 360 t ha^{-1} of this nutrient (EEAA, 2010; FAO, 2014). Similar to N fertilizer, agricultural lime is unaffordable and inaccessible to smallholder farmers in Africa (Tadele, 2017).

Croplands are both a sink and a source of GHG emissions (Kim et al., 2016). It is common practice in much of rural SSA that farmers remove all crop residues after harvest (Suckall et al., 2015). Crop diversity in the continent is more pronounced in West Africa than in other regions and many of the crops planted in this region are unique and not well researched (Tadele, 2017). Cassava is the major crop grown in West Africa (Leff et al., 2004) and the general belief that this crop does not require fertilizer since it can do well in degraded lands, makes farmers barely use fertilizer (Fermont et al., 2010). A mixture of wheat, barley, maize and rice dominates large crop areas in North Africa (Leff et al., 2004). Maize, sorghum, wheat and millet are common staple crops in Southern Africa (Wenzel, 2003; Christiansen, 2008; Tongwane et al., 2016). The only regions globally where a cereal is not the dominant crop are the Caribbean and central Africa (Leff et al., 2004). Production of cereal crops is the major source of GHG emissions in Africa because of the large areas of lands they occupy when compared to other crops (Tongwane et al., 2016). GHG emissions from croplands in SSA depend on both natural variations associated with climate and soil type and management factors including nutrients (particularly fertilization) and crop type (Kim et al., 2016).

In 2005, agriculture contributed between 10% and 12% of total global anthropogenic GHG emissions (Vermeulen et al., 2012). Current understanding of GHG emissions in SSA is particularly limited when compared to the potential the continent has as both a GHG sink and a source (Kim et al., 2016; Boateng et al., 2017). Limited data and information on agricultural production in Africa make it difficult to quantify the contribution that the continent could make towards global mitigation of GHG emissions. This review studied GHG emissions from agriculture in Africa with a view to establishing a synoptic baseline for the continent that would assist in the planning of mitigation activities in the sector. It analyzed characteristics of GHG emissions from the agriculture sector in Africa for the years 1994, 2000, 2005, 2010 and 2014. Emissions from other land use types including forestry were not considered. Only GHG sources based on the Intergovernmental Panel on Climate Change (IPCC) approaches were analyzed and sinks are excluded. The review advances understanding of GHG emissions from agriculture previously presented by other authors (e.g. Valentini et al., 2014) and various publications made by the Food and Agriculture Organization of the United Nations (FAO, 2014, 2015). The major sources of agricultural emissions are identified per agro-ecological region.

2. Approach to this review

The agroclimatological zones in Africa are diverse. They range from the dry barren desert in the North, through the rich soil of the Rift, Nile and Niger valleys, to the southern extremes (Leff et al., 2004). Based on this diversity, Africa can be divided into five broad agro-ecological zones (Table 1). These zones closely resemble regional economic communities of the African Union. Nearly all countries had compiled their first and second communications to the United Nations Framework Convention on Climate Change (UNFCCC) and therefore emissions for the base years 1994 and 2000 were available for the majority. However, few countries have developed third national communications and GHG emissions beyond 2000. Primary data for the years 1994 and 2000 came from national communications and the UNFCCC portal (http://di.unfccc.int/NonAnnex.aspx). In the event that data from national communications were not available in these years, but were reported in a year either before or after them, those data were used to fill the respective gaps. African national GHG inventories and communications are not always consistent and continuous during the reporting periods. Reporting of the emissions is aggregated into broad categories that may not allow detailed analysis of sources by type. For instance, N_2O emissions from agricultural soils, including emissions from synthetic fertilizers, manure and crop residues, are treated as a single reporting category (Tubiello et al., 2013). Emissions from enteric fermentation are aggregated and do not show contributions by animal type. This makes it difficult to perform sensitivity analysis of the emissions. As a result, while national inventories and global databases

Table 1
Representation of African continent into five zones.

	1994	2000	2005	2010	2014		1994	2000	2005	2010	2014
Central Africa						Southern Africa					
Burundi (BI)	FAO	FAO	NC	FAO	FAO	Angola (AO)	FAO	NC	NC	FAO	FAO
Cameroon (CM)	NC	NC	FAO	FAO	FAO	Botswana (BW)	FAO	NC	NC	FAO	FAO
Central African Republic (CF)	NC	FAO	NC	NC	FAO	Lesotho (LS)	NC	NC	NC	NC	FAO
Chad (TD)	$^{+}$NC	FAO	FAO	FAO	FAO	Madagascar (MG)	NC	NC	FAO	FAO	FAO
Congo (CG)	NC	NC	FAO	FAO	FAO	Malawi (MW)	NC	FAO	FAO	FAO	FAO
Democratic Republic of Congo (CD)	NC	NC	FAO	FAO	FAO	Mauritius (MU)	NC^{+}	NC	NC	FAO	FAO
Equatorial Guinea (GQ)	FAO	FAO	FAO	FAO	FAO	Mozambique (MZ)	NC	FAO	FAO	FAO	FAO
Gabon (GA)	FAO	NC	FAO	FAO	FAO	Namibia (NA)	NC	NC	FAO	FAO	FAO
Rwanda (RW)	FAO	NC	FAO	FAO	FAO	Seychelles (SC)	NC^{+}	NC	FAO	FAO	FAO
Sao Tome & Principe (ST)	FAO	FAO	FAO	FAO	FAO	South Africa (ZA)	NC	NC	NC	NC	FAO
						Swaziland (SZ)	NC	FAO	FAO	FAO	FAO
East Africa						Tanzania (TZ)	NC	FAO	FAO	FAO	FAO
Comoros (KM)	NC	FAO	FAO	FAO	FAO	Zambia (ZM)	NC	NC	FAO	FAO	FAO
Djibouti (DJ)	NC	NC	FAO	FAO	FAO	Zimbabwe (ZW)	NC	NC	FAO	FAO	FAO
Eritrea (ER)	NC	NC	FAO	FAO	FAO						
Ethiopia (ET)	NC	NC	NC	NC	FAO	West Africa					
Kenya (KE)	NC	NC	NC	FAO	FAO	Benin (BJ)	NC^{+}	NC	FAO	FAO	FAO
Somalia (SO)	FAO	FAO	FAO	FAO	FAO	Burkina Faso (BF)	NC		FAO	FAO	FAO
Sudan* (SD)	NC^{+}	NC	FAO	FAO	FAO	Cabo Verde (CV)	NC^{+}	NC	FAO	FAO	FAO
Uganda (UG)	NC	NC	FAO	FAO	FAO	Cote d'Ivoire (CI)	NC	NC	FAO	FAO	FAO
						Gambia (GM)	$^{+}$NC	NC	FAO	FAO	FAO
North Africa						Ghana (GH)	NC	NC	NC	FAO	FAO
Algeria (DZ)	NC	NC	FAO	FAO	FAO	Guinea (GN)	NC	FAO	FAO	FAO	FAO
Egypt (EG)	NC	FAO	FAO	FAO	FAO	Guinea-Bissau (GW)	NC	FAO	FAO	FAO	FAO
Libya (LY)	FAO	FAO	FAO	FAO	FAO	Liberia (LR)	NC	FAO	FAO	FAO	FAO
Mauritania (MR)	NC^{+}	NC	FAO	FAO	FAO	Mali (ML)	NC^{+}	NC	FAO	FAO	FAO
Morocco (MA)	NC	NC	NC	NC	FAO	Niger (NE)	NC	FAO	FAO	FAO	FAO
Tunisia (TN)	NC	NC	FAO	FAO	FAO	Nigeria (NG)	NC	NC	FAO	FAO	FAO
						Senegal (SN)	FAO	NC	NC	FAO	FAO
						Sierra Leone (SL)	FAO	FAO	FAO	FAO	FAO
						Togo (TG)	NC	NC	NC	FAO	FAO

*Sudan represents the current Sudan and South Sudan.
$^{+}$NC and NC^{+} represent a year before and after a considered year respectively.

are currently the best bottom-up emissions available, they cannot be objectively compared due to differences in definitions, methods, validation processes and data completeness (Tubiello et al., 2013; Roman-Cuesta et al., 2016). This makes trend analysis of the emissions immensely difficult.

Greenhouse gas emissions data from FAO (2017a, http://www.fao.org/faostat/en/#country) and FAO (2014) were used for the synthesis of emissions in 2005, 2010 and 2014. However, where national data were available, the emissions from the countries were used instead. The FAO (2014) data consisted of comprehensive disaggregated emissions for 2010. These data were also used to determine contributions of each category to the total agricultural emissions. The Emissions Database for Global Atmospheric Research [EDGAR, http://edgar.jrc.ec.europa.eu] (EC-JRC, 2016) data was used to develop consistent time series from 1994 to 2012. EDGAR comprises the CO_2, CH_4 and N_2O emissions and provides an independent estimate of GHG emissions for all countries, thus filling the vacuum in knowledge on the status quo of recent emission trends (Olivier et al., 2017). EDGAR provides global GHG emissions at 0.1° and country levels (Roman-Cuesta et al., 2016). It provides emissions by IPCC' sector, category and GHG type. In EDGAR, emission factors and activity data from 2012 back to 1970 have been updated with revised international statistics (Roman-Cuesta et al., 2016; Olivier et al., 2017).

Greenhouse gas emissions per capita, GDP and hectare were calculated to compare emission intensities between countries. The FAO (2014) data were used to classify the continent's agricultural lands in 2010. Population statistics were obtained from United Nations Statistics database (UNSTATS) (https://unstats.un.org/unsd/demographic-social/products/). GDP statistics per country were obtained from World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG). Global warming potentials of 25 for CH_4 and 298 for N_2O were used to convert these GHGs to their respective CO_2 equivalent emissions [CO_2e] (Forster et al., 2007; Scheutz et al., 2009).

3. Greenhouse gas emissions from agriculture in Africa

This section provides information on GHG emissions in Africa. Subsection 3.1 presents a brief description of agricultural lands in Africa according to total, arable and non-arable lands. Subsection 3.2 discusses total agricultural emissions in Africa, regions of the continent and individual countries. Subsection 3.3 provides emissions by GHG categories. Subsections 3.4 and 3.5 discuss emissions by GHG types and emission' intensities respectively.

3.1. Agricultural lands in Africa

Agricultural activities in Africa in 2010 were undertaken on 1130 million hectares (Mha) of land. Nearly a third of this land is in Southern Africa, a fifth in each of East and West Africa, and a tenth in each of Central and North Africa. Nearly three quarters of agricultural land in Africa is predominantly occupied by permanent paddocks and pastures and a fifth of the land is arable (Fig. 1). Most of the agricultural land (85%) in North Africa is used for pastures as it is not suitable for other forms of agriculture (FAO, 2014). This pattern of land use in the continent makes livestock production the main option (Scholtz et al., 2013). SSA cropland increased from 130.5 Mha in 1961 to 207.3 Mha in 2008 (Fuglie and Rada, 2013). With 13% of the global harvested area, Africa has less cropland than any other part of the world (Leff et al., 2004). Arid deserts and semi-arid savannas comprise 40% of the SSA land area (Rockstrom and Falkenmark, 2015). Arable land area that is in need of adoption of improved soil fertility management practices is at least 150 Mha in Africa (of 173 Mha total arable land) (Lal, 2000). This is a particularly important issue to address because the access to additional available land for agricultural purposes is gradually becoming a

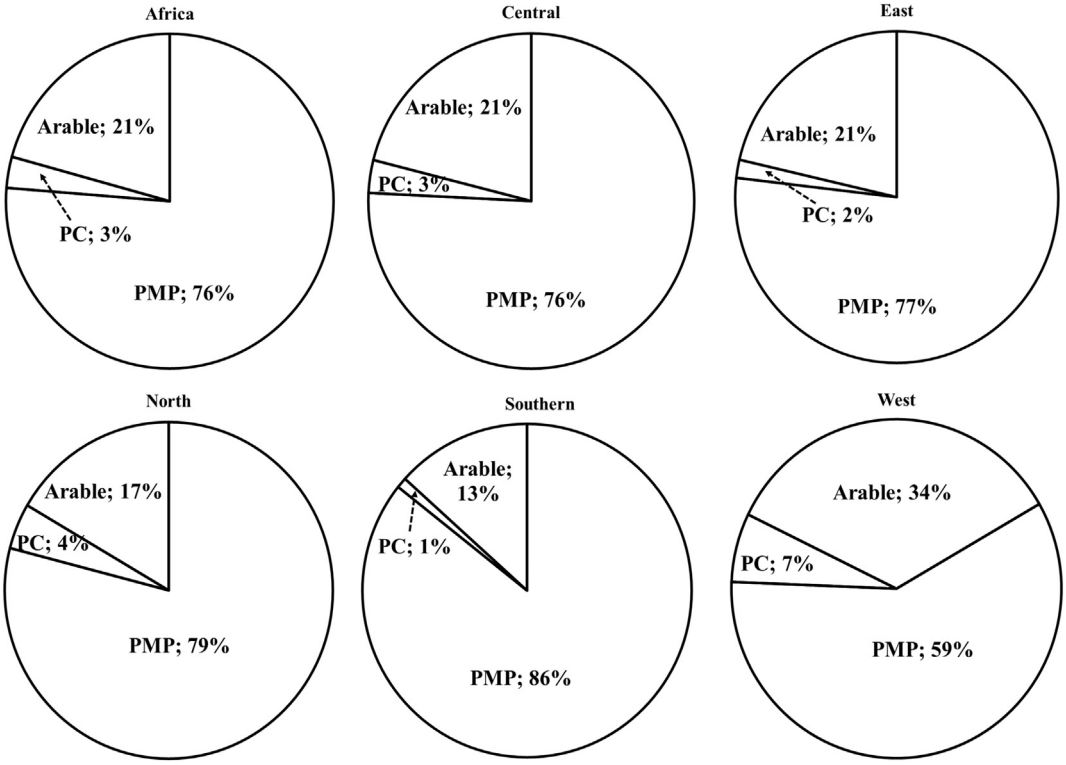

Fig. 1. Agricultural land use in Africa in 2014 (Data source, FAO (2014)). PC – permanent crop; PMP – permanent meadows and pastures.

constraint in many parts of the continent (Salami et al., 2010).

3.2. Agricultural emissions in Africa by regions and countries

Agricultural GHG emissions in Africa vary from region to region. In total, agricultural emissions produced in Africa ranged from 0.44 Gt to 0.54 Gt of CO_2e in 1994 (Table 2). The total emissions rapidly increased to between 0.66 and 0.79 Gt in 2010. In the FAO (2017a) database, the only comprehensive source of data for 2014 indicates that the total emissions in that year were approximately 0.87 Gt. These estimates are comparable to those of Valentini et al. (2014) and to global values in Smith et al. (2007, 2014). Averaged over the period 2000 to 2010, the African continent is the third highest producer of agricultural GHG emissions behind Asia and the Americas (Tubiello et al., 2013; FAO, 2014, 2015). The emissions presented in this work are exclusive of CO_2 from lime and urea.

Agricultural GHG emissions in the continent increased by between 2.9% and 3.1% per annum between 1994 and 2010. These rates of increase are more than double the global average. Between 2000 and 2010, global agricultural emissions increased by 1.1% annually, reaching 4.6 Gt CO_2e in 2010 (Tubiello et al., 2013). Emissions in East Africa increased by 4.7% per year between 1994 and 2014, 2.9% in Southern Africa, 1.2% in Central Africa and 1.1% in North Africa. There was a decrease of 3.0% in annual emissions between 1994 and 2000 in East Africa, and increases of 5.7% in the central part of the continent, 2.2% in the West and 1.8% in the North. This decline can be attributed to quality of activity data in these two years that defined the first attempts of GHG development by developing countries. Systems and data to compile GHG inventories hardly existed in many countries and the subject was poorly understood. Generally, agricultural emissions in developing countries are increasing at a faster rate than those in developed countries (Tubiello et al., 2013). This annual high rate of increase may make Africa a major producer of emissions in the near future. Emissions of enteric fermentation grew rapidly in Africa between 2000 and 2010 with an average annual rate of 2.4% (Smith et al., 2014).

Table 2
Total agriculture GHG emissions based on country and FAO data and [EDGAR] (Gt) in Africa between 1994 and 2014.

	1994	2000	2005	2010	2014
Total Africa	0.535 [0.438]	0.587 [0.505]	0.739 [0.570]	0.785 [0.656]	866,112
Central Africa	0.060 [0.029]	0.081 [0.033]	0.07,9 [0.037]	0.074 [0.039]	74,567
East Africa	0.154 [0.148]	0.127 [0.170]	0.245 [0.199]	0.247 [0.243]	298,312
North Africa	0.059 [0.048]	0.065 [0.058]	0.066 [0.065]	0.067 [0.067]	72,176
Southern Africa	0.150 [0.111]	0.186 [0.127]	0.190 [0.131]	0.229 [0.140]	234,625
West Africa	0.112 [0.092]	0.129 [0.106]	0.158 [0.126]	0.168 [0.147]	186,432

Regional contributions to total agricultural GHG emissions of the continent and their respective temporal increases differ significantly. East Africa is the largest source of the agricultural emissions (Fig. 2; Table 3). Approximately a third of the continent's total agricultural emissions come from this region. As a result of the large livestock population in Ethiopia, a total of 94% of national agricultural emissions in 2013 were from enteric fermentation (MEF, 2015). In general, Southern Africa produced approximately three tenths of the total emissions from agriculture in Africa in 1994 and 2014. West Africa contributed a fifth of the total GHG emissions while each of Central and North Africa produced nearly a tenth of total GHG emissions from agriculture in Africa. North Africa, the most arid region in the continent, was the lowest overall producer of agriculture emissions in Africa.

The former Sudan was the largest producer of agricultural GHG emissions in Africa, followed by Ethiopia, Nigeria and South Africa. The profile of the highest GHG producing countries changed slightly in 2014 compared to 1994 with Ethiopia and Nigeria significantly increasing their rankings to second and third respectively. The largest emitting

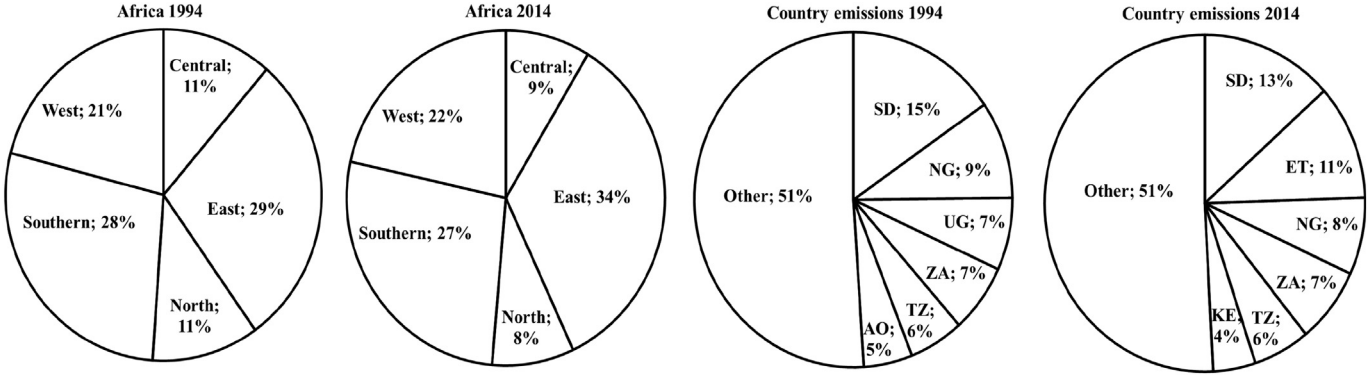

Fig. 2. Agricultural GHG emissions by region in Africa in 1994 and 2014.

countries in Central Africa are the Central African Republic, Cameroon and Chad. In East Africa the main source countries are Sudan, Ethiopia and Kenya, while Egypt, Morocco and Algeria are the largest producers in North Africa. South Africa and Tanzania dominate emissions in Southern Africa while Nigeria is by far the largest emitter in West Africa.

The EDGAR and FAO agricultural emissions overestimate the GHG values contained in the national communications (Fig. 3), being generally 40% and 30% higher than the estimates in the national communications and inventory reports respectively. These uncertainties in agricultural GHG emissions can be due to several factors. The default IPCC emission factors may not be representative of the continent in many aspects. The animal numbers and agricultural lands in African countries are mostly inconsistent based on the source of information. Current GHG emissions from soils in Africa are based on IPCC emission factors which implicitly ignore important characteristics of African soils and management practices of smallholder farmers, both of which could alter emissions substantially (Hickman et al., 2011; Albanito et al., 2017). These data shortfalls make African estimates of N_2O emissions challenging (Liu et al., 2010; Hickman et al., 2011; MEWT, 2016). Current data, although limited to a few studies, suggest that mean N_2O emission factors can be as high as 1.4% for Africa, 40% higher than default IPCC factors (Albanito et al., 2017). Moeletsi et al. (2017) found that emissions from enteric fermentation calculated using country-specific emission factors were more than a third higher than those obtained through default factors. Moreover, general discussions in the national communications and GHG inventories are for the whole AFOLU (Agriculture, Forestry and Land Use). The inclusion of emissions from grasslands and savanna burning can change the profile of agricultural emissions significantly (Hickman et al., 2011). The dominant role played by both CH_4 and N_2O emissions in Africa highlights the importance of reducing these uncertainties for improving continental emission estimates (Hickman et al., 2011).

3.3. Agricultural emissions by GHG categories

Agricultural GHG emissions differ widely by categories, country and time. Enteric fermentation and managed soils are the major sources of agricultural emissions in many African countries. Generally, enteric fermentation produces not less than a fifth in most of the emissions in the countries that presented disaggregated GHG estimates in their national communications and GHG inventory reports. On the contrary, analysis of the emissions from EDGAR indicate that about 57% of the total agricultural emissions in Africa are from enteric fermentation. The EDGAR estimates are consistent with FAO values which indicate that on average, enteric fermentation contributed nearly half of Africa's total agricultural GHG emissions in 2014 (Fig. 4). Country emissions that are consistent with EDGAR are Tanzania (Majule et al., 2014) and South Africa (DEA, 2016).

Pasture, range and paddock is the second largest producer of agricultural GHG in the continent. This category emitted nearly a third of total agricultural emissions in Africa. It produces large emissions because pastoral and mixed livestock farming systems remain the major contributor to rural livelihoods and the national economies of many African nations (Koneswaran and Nierenberg, 2008; Gerber et al., 2013; Zougmoré et al., 2016). The category that produces the third largest overall agricultural emissions is manure management. GHG emissions from manure (includes manure management and fertilizer) accounted for nearly 6.5% of total emissions from the sector.

Growing rice produces 3.7% of agricultural emissions in the continent. The highest emissions from rice production are in tropical West Africa (Carlson et al., 2016). Unlike the more homogeneous GHG emissions from livestock, emissions from croplands are diverse (Roman-Cuesta et al., 2016). Other studies (e.g. Ba, 2016; Tongwane et al., 2016) showed that production of staple cereal crops in many African countries account for the largest sources of GHG emissions from fertilizer. GHG emissions from crops in most parts of Africa are predominantly from fertilizer applied during rice and maize productions (Ba, 2016; Sheahan and Barrett, 2017). Application of manure to agricultural soils during production of field crops can contribute not less than 5.2 million tonnes of CO_2e emissions in South Africa (Tongwane et al., 2016). Maize is a major commodity that is produced in many parts of the continent and overall emissions can be large (Leff et al., 2004; Tongwane et al., 2016). There are increases of emissions in all categories and regions of the continent except for rice production in North Africa where there is a general decrease of 1.1% per year. Globally, emissions from enteric fermentation increased by 0.95% between 1961 and 2010. In Ghana, GHG emissions from enteric fermentation in 2012 increased by 27% and 40.3% above 2000 and 1990 levels respectively (EPA, 2015).

Organic soils prominent in East Africa are also important sources of GHG emissions. About 35 thousand Gg of CO_2e were from cultivated organic soils in East Africa in 2010 (Batjes, 2004; FAO, 2014). There are small emissions from management of crop residues and organic soils in the continent. This is because a large amount of agricultural waste is openly burned in the field or grazed. Savanna burning and grassland fires represent an additional substantial source of emissions in Africa, roughly equivalent to emissions from livestock, much of which can be attributed to land preparation (Hickman et al., 2011). Prescribed burning of savannas and agricultural soils contribute approximately a third of agricultural emissions each in Zambia, ahead of enteric fermentation with a quarter (MLNREP, 2014). There is a similar contribution of the latter in Zimbabwe, which makes this source category the second largest producer of agricultural emissions after enteric fermentation in the country (MEWC, 2016).

Table 3
Agricultural emissions in Africa by GHG category and type (Data source: EDGAR).

	1994		2000		2005		2010	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
Total	0.438		0.505		0.570		0.656	
Africa	0.294	0.144	0.336	0.169	0.379	0.191	0.438	0.218
Enteric fermentation	0.251		0.291		0.328		0.374	
Rice	0.030		0.031		0.036		0.046	
Manure management	0.009	0.003	0.011	0.003	0.012	0.004	0.014	0.005
Direct soil		0.020		0.024		0.028		0.031
Pasture, range and paddock		0.109		0.127		0.143		0.163
Indirect soil		0.012		0.014		0.016		0.018
Burning agricultural waste		0.001		0.001		0.001		0.001
Sub-Total	0.029		0.033		0.037		0.039	
Central Africa	0.020	0.010	0.022	0.011	0.024	0.012	0.026	0.013
Enteric fermentation	0.016		0.019		0.021		0.022	
Rice	0.002		0.002		0.002		0.002	
Manure management	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.001
Direct soil		0.001		0.001		0.001		0.001
Pasture, range and paddock		0.007		0.008		0.009		0.010
Indirect soil		0.001		0.001		0.001		0.001
Burning agricultural waste		0.000		0.000		0.000		0.000
Sub-Total	0.148		0.170		0.199		0.243	
East Africa	0.099	0.048	0.114	0.056	0.133	0.066	0.163	0.080
Enteric fermentation	0.099		0.114		0.133		0.163	
Rice	0.006		0.007		0.008		0.013	
Manure management	0.004	0.000	0.004	0.001	0.005	0.001	0.006	0.001
Direct soil		0.002		0.003		0.004		0.004
Pasture, range and paddock		0.042		0.048		0.056		0.069
Indirect soil		0.003		0.004		0.004		0.005
Burning agricultural waste		0.000		0.000		0.000		0.000
Sub-Total	0.048		0.058		0.065		0.067	
North Africa	0.031	0.018	0.035	0.023	0.039	0.026	0.039	0.028
Enteric fermentation	0.025		0.029		0.033		0.034	
Rice	0.005		0.005		0.005		0.004	
Manure management	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.000
Direct soil		0.006		0.008		0.009		0.010
Pasture, range and paddock		0.010		0.012		0.013		0.014
Indirect soil		0.002		0.003		0.004		0.004
Burning agricultural waste		0.000		0.000		0.000		0.000
Sub-Total	0.111		0.127		0.131		0.140	
Southern Africa	0.072	0.040	0.082	0.045	0.084	0.047	0.091	0.050
Enteric fermentation	0.062		0.071		0.073		0.076	
Rice	0.007		0.007		0.007		0.011	
Manure management	0.002	0.001	0.002	0.001	0.002	0.001	0.002	0.001
Direct soil		0.008		0.008		0.009		0.010
Pasture, range and paddock		0.028		0.032		0.033		0.034
Indirect soil		0.003		0.003		0.004		0.004
Burning agricultural waste		0.000		0.000		0.000		0.000
Sub-Total	0.092		0.106		0.126		0.147	
West Africa	0.063	0.029	0.072	0.034	0.086	0.040	0.100	0.048
Enteric fermentation	0.049		0.058		0.068		0.079	
Rice	0.011		0.011		0.014		0.016	
Manure management	0.002	0.001	0.003	0.001	0.003	0.001	0.004	0.001
Direct soil		0.003		0.004		0.004		0.005
Pasture, range and paddock		0.022		0.026		0.031		0.036
Indirect soil		0.002		0.003		0.003		0.004
Burning agricultural waste	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.000

3.4. Agricultural emissions by GHG type

Two-thirds of GHG emissions from the agriculture sector in Africa are from CH_4 and a third is from N_2O. Enteric fermentation contributed nearly 85% of total African agricultural CH_4 emissions between 1994 and 2010 (Fig. 5, Table 3). The ratio of enteric fermentation to total regional CH_4 is highest in East Africa and lowest in West Africa. The contribution of rice production to total CH_4 emissions is relatively constant in most regions except Central and North Africa. Rice production in Central Africa emitted 13%, 8% and 9% of agricultural emissions in 1994 and 2000 and 2010 respectively. The contribution of rice production to total agricultural CH_4 emissions in North Africa decreased gradually to 9% in 2010. On the other hand, the fraction contributed by rice production in West Africa remained relatively constant at 17% over the years. The highest agricultural CH_4 emissions in Africa come from East Africa with 42% of the continent's total in 2010. During the same period, the contribution of Southern and North Africa to Africa's total declined from 28% to 21% and 13% to 9% respectively while that of West Africa increased from 19% to 23%. The contribution of agricultural CH_4 emissions in Central Africa remained constant at 6–7% of the continent's total. Manure management and burning of agricultural waste account for less than 5% of total agricultural CH_4 emissions in the continent.

The pasture, range and paddock category produces nearly three-quarters of N_2O emissions, followed by 14% from direct soil management and 7–9% from indirect soil emissions. This is consistent with the results of Hickman et al. (2011). East and West Africa have the highest fractions of emissions from pasture, range and paddock. There is a

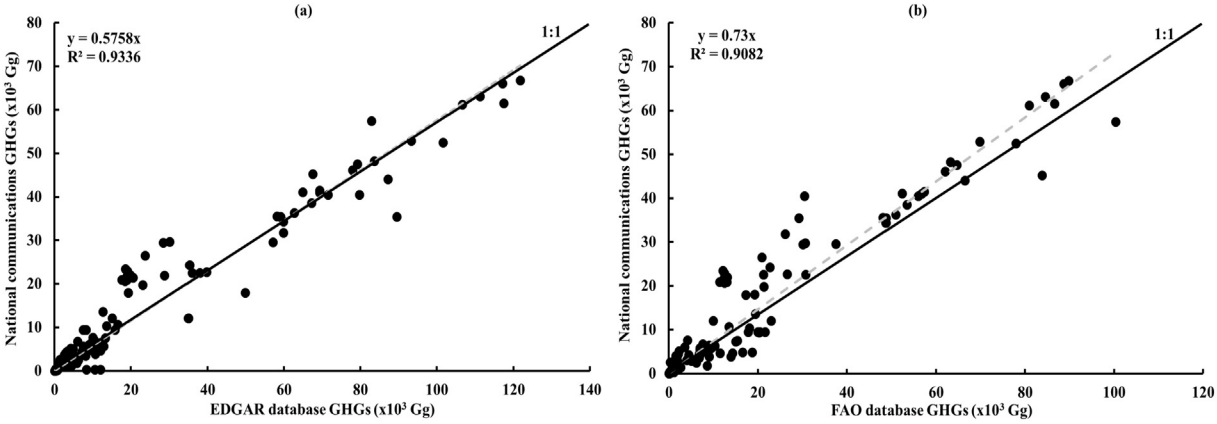

Fig. 3. Comparison of agricultural GHG emissions from African national communications and (a) EDGAR, and (b) FAO.

slight but gradual reduction of the contribution of pasture, range and paddock to total N_2O emissions in many regions of the continent with time. The contribution decreased from 71% in 1994 to 69% in 2010 in Southern Africa, and from 55% to 49% in North Africa during the same period. While the ratio of N_2O emissions from pasture, range and paddock to total agricultural emissions are generally decreasing, there are gradual increases of emissions from soil and manure managements. Currently, there are large increases of direct soil N_2O emissions in the continent (Hickman et al., 2011). North Africa is the only region in the continent whose N_2O emissions from soil contribute nearly a third of total regional N_2O emissions. High GHG emissions from manure management and application in North Africa are mainly due to fertilizer application probably in irrigated cropping systems and a growing population of poultry birds (EEAA, 2010; FAO, 2014). Southern Africa is the second largest source of N_2O emissions from soils.

3.5. Agriculture GHG emission intensities in Africa

Emissions per capita for the year 2005 reflect the average contributions of the citizenry and emissions per GDP show the emissions produced per unit value of economic productivity. Agricultural GHG emission intensities vary significantly between the countries and regions (Fig. 6). Emission intensities are highest in East Africa and lowest in North and Central African countries. These rates suggest that GHG mitigation potential from agricultural emissions is highest in East Africa compared to other parts of the continent.

Generally, least developed countries have high intensities compared to other African countries. Highest intensities in countries with lowest economies may indicate that levels of technologies employed during agricultural production are still poor and less efficient. They also show that the economies of poor countries depend on carbon intensive agriculture. This suggests that the economic output as a function of agricultural emissions is higher in poorer countries than the countries with larger GDPs. This is particularly important considering that agriculture is frequently the largest contributor to the GDP and about two thirds of manufacturing value-added is based on agricultural raw materials (Branca et al., 2012). When compared to other parts of the world, developed countries have high absolute emissions but significantly lower emission intensities than their developing counterparts due to improved livestock diets, genetics, health and management practices (Herrero et al., 2016). Ethiopia has the largest emission intensities in the continent, followed by Eritria and the Central African Republic. In Southern Africa, highest emissions per capita are in Namibia, Botswana, Zambia and Angola. Highest emissions per GDP in this region are found in Madagascar, Zambia and Tanzania. Highest intensities in West Africa are in Mali, Burkina Faso and Niger. The intensities for all these countries are generally higher than the average value for Africa (0.80 Mt. CO_2e per capita, and 0.72 kg CO_2e per GDP). With regard to the spatial distribution of livestock emission intensities, SSA is the global hotspot (Herrero et al., 2013).

GHG emissions per type of agricultural land are highest in East Africa, followed by West and Central Africa (Fig. 7). East Africa maintains the highest rates of enteric fermentation emissions per pasture land, followed by West and North Africa. Annual livestock emissions average 1.1 t CO_2e ha^{-1} of grazing land for East African countries and 0.50 t CO_2e ha^{-1} for West African countries (Brown et al., 2012).

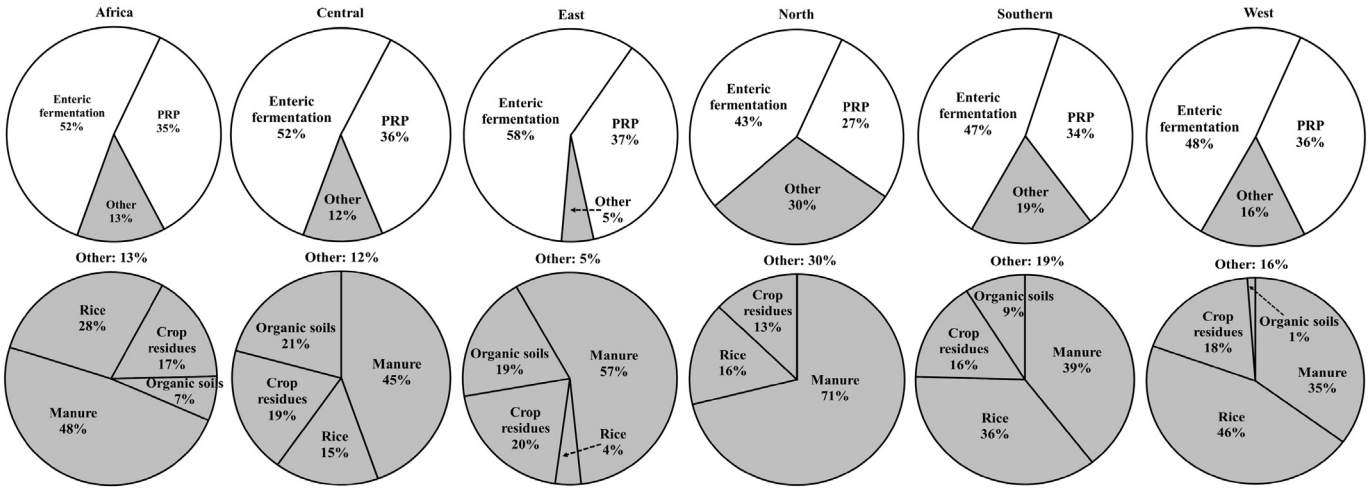

Fig. 4. Contributions of different categories to agricultural GHG emissions in Africa in 2010. Data source FAO (2014).

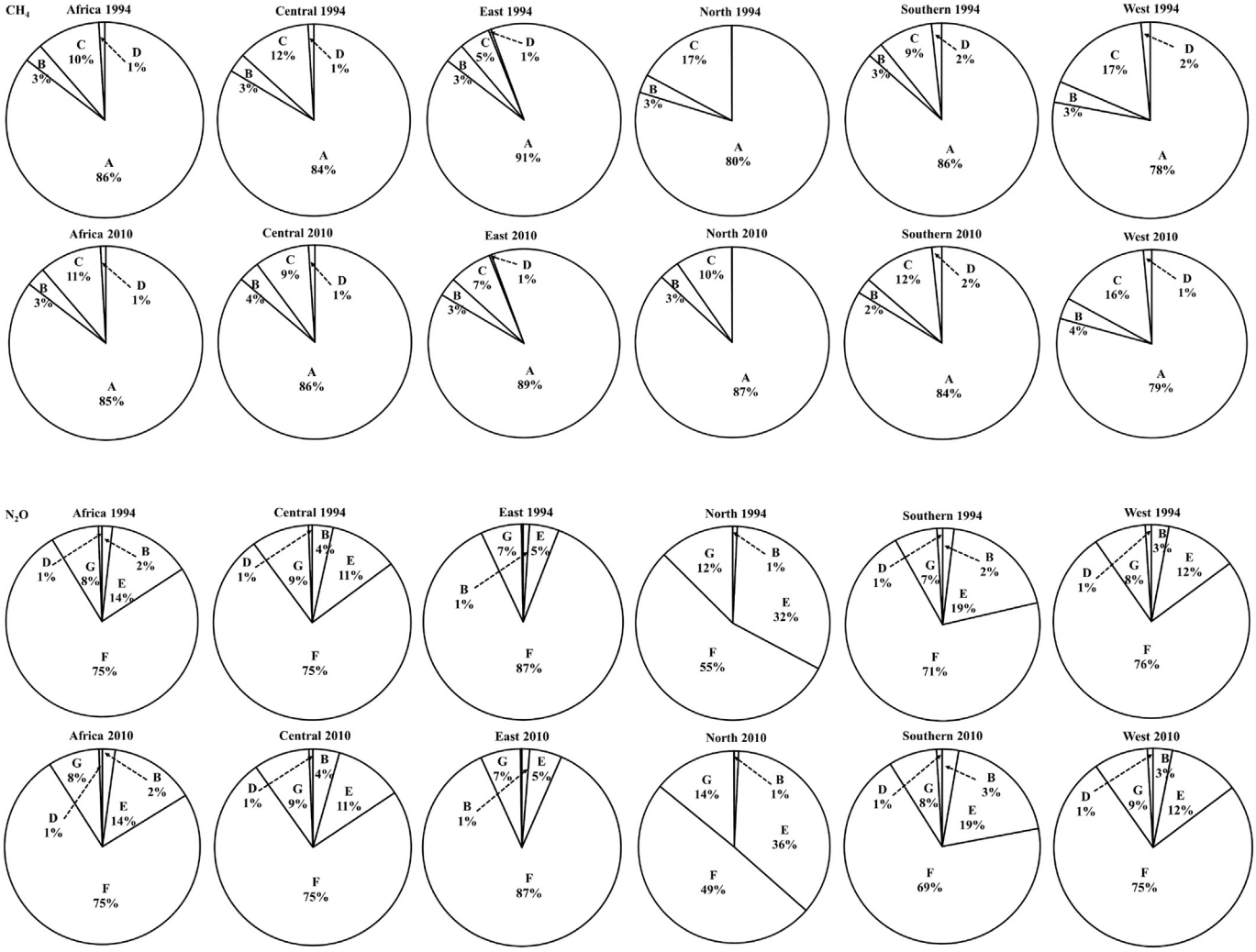

Fig. 5. Agricultural CH_4 and N_2O emissions by sources in Africa and its regions. (A- Enteric fermentation; B- Manure management; C- Rice; D- Burning agricultural waste; E- Direct soil emissions; F- Pasture, range and paddock; G- Indirect soil emissions)

The annual rates for Ethiopia were the highest by far at 2.5 t CO_2e ha^{-1}, which is to be expected given the high number of cattle and other ruminants present in that country (Brown et al., 2012).

4. Policy and strategies for GHG mitigation from agriculture in Africa

Africa needs to develop climate policies that will reduce the rapid growth of GHG emissions. The policies and measures to protect the climate system against human-induced change must be appropriate for the specific conditions of each country and should be integrated with national development programmes, taking into account that economic development is essential for adopting measures to address climate change (UN, 1992). The resurgence of input subsidy programmes in Africa has arguably been the continent's most important agricultural policy development in recent years (Jayne and Rashid, 2013). However,

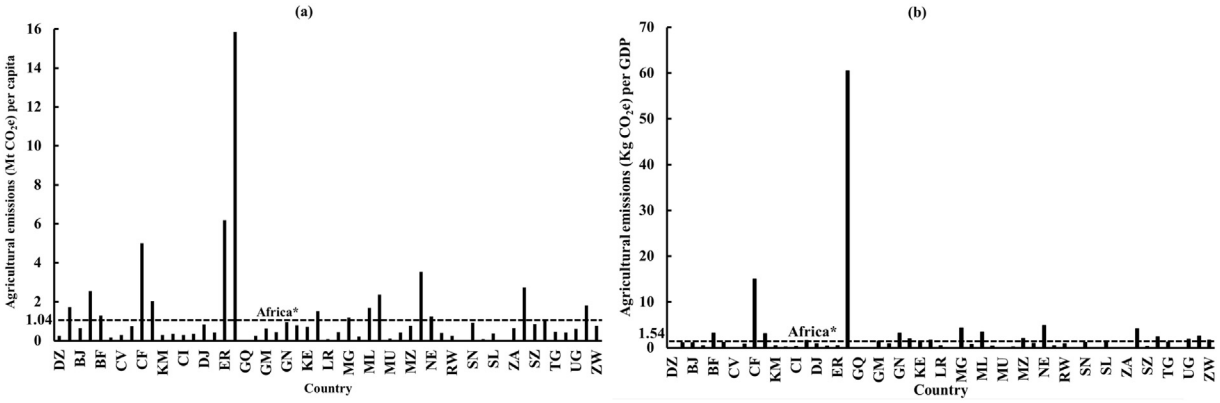
(a)
Agricultural emissions (Mt CO2e) per capita
Africa*
1.04
Country
DZ BJ BF CV CF KM CI DJ ER GQ GM GN KE LR MG ML MU MZ NE RW SN SL ZA SZ TG UG ZW
(b)
Agricultural emissions (Kg CO2e) per GDP
Africa*
1.54
Country
DZ BJ BF CV CF KM CI DJ ER GQ GM GN KE LR MG ML MU MZ NE RW SN SL ZA SZ TG UG ZW

Fig. 6. Intensity of agricultural GHG emissions per (a) capita, and (b) GDP. *Africa's average intensity excluding rates from Ethiopia.

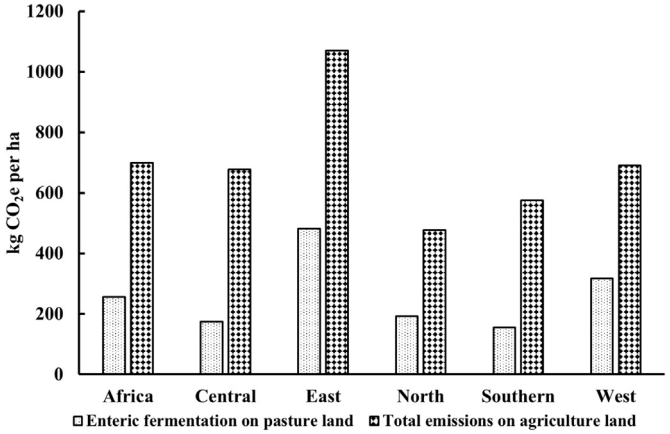

Fig. 7. Variability of emission intensities per agricultural land and regions of Africa in 2010.

this policy has increased the use of inorganic fertilizer in subsistence farming thus impacting negatively on mitigation initiatives of the continent.

Currently, Africa's approach to climate change focusses more on adaptation than mitigation. Adapting to climate change in SSA is likely to cost thousands of millions of dollars every year (Suckall et al., 2015). This is based on the high vulnerability of the continent to climate change. Nearly two thirds of the countries in the continent are regarded as least developed, the most vulnerable group of countries to climate change. A defining factor of African agriculture is the dominance of resource-poor smallholder farmers with a strong priority on food security (Mbow et al., 2014).

The African Union is in the process of developing a climate change strategy for the continent that puts adaptation as an overriding priority (AU, 2014). In most parts of Africa, climate change mitigation focusses on reforestation and forest protection (Mbow et al., 2014), and mainstreaming focusses more on the energy sector (SADC, 2010). East and Southern African countries jointly developed a 5-year programme (2010–2016) that focussed on climate change adaptation and mitigation with the key objective of addressing the impacts of climate change through adaptation and mitigation through climate-smart agriculture (CSA) (Viljoen, 2013). Similarly, recent developments at a political level in West Africa give hope for large-scale CSA adoption for improved resilience to climate change and food security in the region (Zougmoré et al., 2016). CSA is defined by three objectives: firstly, increasing agricultural productivity to support increased incomes, food security and development; secondly, increasing adaptive capacity at multiple levels (from farm to nation); and thirdly, decreasing GHG emissions and increasing carbon sinks (Campbell et al., 2014). CSA provides adaptation benefits through moisture conservation by mulching and minimum disturbance of the soil which limits evaporation, and crop residues left on the field also improves soil fertility through decomposition (Campbell et al., 2014). Improved soil fertility can assist with the decrease of inputs of synthetic N fertilizer that results in a net decrease of GHG emissions.

Sustainable development in Africa should consider both climate change adaptation and mitigation activities concurrently. Policies aimed to increase income and improve food security can be beneficial to farm households that own local cattle if such households are encouraged to adopt improved livestock diets, while those targeting poverty reduction should aim to promote adoption of improved cow breeds (Shikuku et al., 2017). On the other hand, livestock production systems are in a transition to a more sedentarized but possibly more intensified mode that needs proper policy support (Zougmoré et al., 2016).

Mitigation measures in the livestock sector could include technical and management options that promote reduction of GHG emissions from livestock: efficient livestock feeding systems, balanced feed rations and efficient manure management (Zougmoré et al., 2016). The major technical mitigation potential of GHG emissions from livestock is probably to be found in areas where both measures of emission intensity are high (Gerber et al., 2013). A good mitigation option for ruminants is the provision of forages of higher digestibility, and inclusion of energy-dense feeds (e.g. cereal grains) in the ration (Herrero et al., 2016). There is a need to promote improved feeding strategies and introduce more efficient breeds of livestock in order to achieve improved food security, increased productivity, reduced poverty, and reduced CH_4 emissions intensities (Gaitan et al., 2016; Shikuku et al., 2017). This is particularly important considering that enteric fermentation is the largest source of emissions in the continent.

A greater input of N to the soil is urgently needed to satisfy the basic needs of an increasing African population (Hickman et al., 2011; Saghir, 2014). However, correct management practices that include rate and timing of N application during crop production need to be considered to prevent an increase in soil infertility, leaching and N_2O emissions from N that is not used by crops. Better timing of fertilizer application, precision and effectiveness through improved placement of appropriate quantities of applied inputs (AGRA, 2014) can reduce amounts of N lost and not used by crops during crop production in Africa – amounts that end up releasing GHG emissions. Investments focussing on input intensification only increase productivity of some factors but can put pressure on the environment (Valin et al., 2013).

Maximization of agriculture's adaptation and mitigation potential will require investments in technological innovation linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are inclusive of smallholder farmers (Vermeulen et al., 2012). Mechanization could contribute to reduction of N related GHG emissions (AGRA, 2014). The scale of mitigation of agricultural GHGs in Africa is dependent on support from developed countries. Even though it is important that the technology be identified through robust research and then be developed and tested locally, the continent may lack the capacity to carry out this process. Innovation and capacity building are required for improved farming practices and measurement techniques, and for appropriate institutions and incentives (Vermeulen et al., 2012). Through technology needs assessments, the African countries identified adaptation technologies for agriculture with mitigation obtaining secondary benefits.

The complex and traditional structure of the agriculture sector in Africa has prevented it from optimally benefiting from international financing mechanisms. Agriculture in general, and extensive livestock particularly in Africa, suffers from inherent biases in the current mitigation financing mechanism (Zougmoré et al., 2016). The World Bank developed a medium-term plan to scale-up lending to US$3 billion a year, with ambitious targets in key thematic areas – irrigation, land administration, access to technology, inputs, financial services and markets, and CSA – so that SSA can benefit fully from the transformative opportunity (Saghir, 2014). Part of the contribution of the World Bank is to assist with land administration that can ultimately lead to selling of carbon credits from the continent (Saghir, 2014). South Africa plans to implement a carbon tax in all the sectors of the economy including agriculture (Treasury, 2017) and Nigeria is planning a similar approach.

Although actions taken to improve food security and help farmers adapt to climate change may often have significant mitigation co-benefits, they may also have higher upfront costs including labour and mechanization costs (Campbell et al., 2014). Another key constraint could be that CSA technologies are not well targeted because trade-offs among interventions are not well understood (Aggarwal et al., 2018). Lack of evidence of how innovations can be practically incorporated into agricultural systems remains a major constraint (Musa, 2015; Suckall et al., 2015; Aggarwal et al., 2018). To achieve synergy between adaptation, mitigation and development, interdisciplinary approaches

that balance stakeholders' immediate local needs with longer-term global climate issues is required (Suckall et al., 2015). Furthermore, synergies need to take into account temporal and spatial scales, including inter-linkages between sectors, as a gain in one sector may lead to a loss in another (Suckall et al., 2015). For example, the use of legumes in pastures has been estimated to sequester 200 $MtCO_2e$ per year globally, though this could increase soil N_2O emissions by 60 $MtCO_2e$ per year (Herrero et al., 2016). In general, smallholder farmers and probably African farmers in general are ready to trade-off among the three goals of CSA, and the aspects of such practices that are most desirable to smallholder farmers are increased production and resilience (Musa, 2015).

5. Conclusions

Agricultural activities in Africa emitted between 0.44 Gt and 0.54 Gt CO_2e in 1994, 0.66 Gt and 0.79 Gt in 2010 and a total of 0.87 Gt in 2014 which was a tenth of the sector's global GHG emissions. Eastern and Southern Africa were the major contributors with a third and 27% of the total emissions respectively. West Africa accounted for 20% of the total emissions and each of Central and North Africa produced 11% of the total emissions. The annual rate of growth of the emissions in the continent is 2.9% although the rates differ between regions. The general increase of food demand in the continent and abroad, intensification of agricultural production with additions of more inputs of synthetic fertilizer, and expanding agricultural lands are the major factors that cause this rapid growth of emissions. Most national GHG reports and communications to the UNFCCC do not provide sufficient details regarding GHG sources but indications are that enteric fermentation and soil management are the main sources of GHG agricultural emissions in the continent. Data limitations in Africa increase uncertainty in the results and prevent detailed analysis that is essential for both domestic and international planning for mitigation. The emissions per capita and per unit of economy show that the least developed countries have the highest intensities, indicating the heavy reliance of the citizens' livelihoods on carbon intensive agriculture.

Modern technology and general approaches to manage agricultural production are required in Africa so that the sector can develop sustainably. Improvement of mixed agricultural production systems practised in Africa needs customized solutions. Mitigation of GHG emissions from management of activities in agriculture has to be matched and implemented together with measures that strengthen the resilience of the sector. Addressing a single component of this strongly connected sector without putting similar efforts into the other may compromise the anticipated outputs. Therefore, the current focus of African countries to strengthen resilience of economic systems from the damaging effects of climate change, if planned holistically, can address GHG reductions in agriculture which is the main source of livelihoods in the continent and also a key producer of the overall emissions. Research focussing on improving the emission factors in Africa can reduce current levels of uncertainties in the emissions. This may require external funding and expertise from outside the continent since internal resources may not suffice. Sustainable data generation and storage systems need to be developed in the continent for future referencing and archiving. Current ad hoc mechanisms employed not only to manage agricultural GHG activities but the whole climate change processes need to be changed. Different components of the work has to be institutionalized appropriately according to mandates and comparative strengths of establishments that are available or need to be formed to do the work in the respective countries.

Acknowledgements

Dr. Thomas Fyfield of the Agricultural Research Council proof-read this manuscript.

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